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EFFECTS OF GASOLINE REMOVAL ON THE HEATING VALUE OF NATURAL GAS

BY

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EFFECTS OF GASOLINE REMOVAL ON THE HEATING VALUE OF NATURAL GAS.

By Donald B. Dow.

INTRODUCTION.

The question as to the loss of heating value of natural gas through the removal of the gasoline vapor that the gas contains has caused much controversy in which the public in general and legislative bodies and public utilities commissions have taken part. Notwithstanding the several sources[a] of information available, the general understanding in regard to this question remains unsettled.

In the hope that this uncertainty may be removed the Bureau of Mines has made a comprehensive investigation of the problem through its petroleum station at Bartlesville, Okla. The natural gas examined included gas being treated at gasoline plants in many different fields, not only "dry" gas treated by absorption, but also rich "casing-head" gas treated by this method, in order that definite information might be available as to the effect of recovering gasoline from natural gas of varying richness and from different localities. The results of the investigation are presented in this report.

In general, the decrease in heating value of natural gas from removal of the gasoline vapor is overestimated. The loss in the B. t. u. value of the "dry gas" ordinarily supplied to the domestic consumer was found to be about 2 per cent after the gasoline vapor had been removed, but for "casing-head" gas, which rarely reaches the domestic consumer, the percentage loss is larger. As the gasoline vapor in natural gas is usually accompanied by proportionate amounts of other constituents of high heating value, a high gasoline content usually indicates a gas of high heating value even after the gasoline has been removed.

[a] Wyer, S. S., Natural gas; its production, service, and conservation, Bull. 102, part 7, Smithsonian Inst., 1918, pp. 25–26; Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods, Bull. 120, Bureau of Mines, 1917, 64 pp.; Biddison, P. M., The reduction in heating value due to recovery of gasoline content very slight, Natural Gas and Gasoline Jour., vol 11, August, 1917, p. 213.

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This report, in addition to presenting data on the heating values of the gas before and after treatment, for the plants examined, with analyses of the gas samples, also discusses the advantages and disadvantages of gasoline plants in their effects on heating value of the gas treated, the function of such plants with respect to maintenance of pressure in gas lines, and the losses by leakage.

It is hoped that this report will be of help to gas consumers and producers and to Federal and State organizations and commissions interested in the subject.

ACKNOWLEDGMENTS.

In the preparation of this paper the writer depended largely on the cooperation of plant operators for obtaining samples and plant data, and gratefully acknowledges their valuable assistance. Special thanks are due H. Harrison, E. T. Buckley, Richard Battle, D. L. Newton, J. C. Rector, John S. Zink, W. A. Goldtrap, Guy Goodwin, and F. H. Crawford for their whole-hearted interest and generous help.

W. P. Dykema and Roy O. Neal, of the Bureau of Mines, were ever ready with valuable suggestions, and through their aid have made this paper possible.

REVIEW OF THE SITUATION.

The magnitude of the question under consideration can be clearly realized by noting the amount of gas being treated yearly and the large number of consumers who would be affected should the treatment of natural gas for removal of gasoline lower its heating value appreciably. In the year 1917 [a] there was produced in this country about 49,000,000 gallons of gasoline by the absorption process. This output involved the treatment of about 349,000,000,000 cubic feet of natural gas, the gas being distributed for domestic and industrial consumption and yielding about a fourth of the total amount of gasoline that is recovered from natural gas by all methods.

It might also be added that in the same year the average price of natural gas for domestic purposes was about 30 cents per 1,000 cubic feet, and in the States of New York, Pennsylvania, Ohio, West Virginia, Kansas, Oklahoma, and California there were 2,167,000 consumers located in more than 2,100 cities and towns.[b]

The common supposition among a large number of natural gas consumers and many legislators is that when gasoline vapors are removed from natural gas the heating value of the gas must be greatly

[a] Northrop, J. D. Natural gas and natural-gas gasoline in 1917, Mineral Resources United States, pt. 2, U. S. Geol. Survey, 1919, p. 1120.

[b] Northrop, J. D., Work cited, p. 1059.

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reduced. This assumption is based on the fact that gasoline vapors have a higher heating value per cubic foot than the hydrocarbons that remain after the gas passes through the plant. When this conclusion is reached the matter is taken up by utilities commissions, and the gas companies are rather deeply involved for the time being, until extensive tests are made which usually show actual conditions and the truly small loss of heat units. However, it seems that even after satisfactory explanations are made the question is often not settled permanently, for in a year's time it may reoccur, and the entire situation is reinvestigated. Such investigation, of course, is an expense to the public as well as the gas companies, and as the results always give the same information (as far as the writer has been able to learn), no advantage is gained.

CHARACTER OF NATURAL GAS EXAMINED.

The amount of gasoline vapor present in natural gas depends not only on the origin of the gas but also on the pressure to which a gas is subjected, because the higher hydrocarbons are liquefied by pressure and the amount of gasoline remaining in the gas will depend upon its partial vapor pressure[a]—that is, with increased pressure the gasoline content becomes lower. As the casing-head gas that has a large gasoline content is produced in relatively small quantities, it is not used much as commercial gas except when the price obtainable for natural gas warrants the expense of gathering lines for these small volumes, or where there is a large volume of residual gas from an adjacent gasoline plant. The air content due to pumping the gas under a vacuum is also an objectionable feature that precludes the use of low-pressure gas for commercial purposes. Consequently the high-pressure gas or dry gas is of greater interest in this investigation. Hence this paper considers absorption plants rather than compression plants, as the absorption process is the only commercial method by which the gasoline can be extracted from dry gas.[b]

Although compression plants are most commonly used in the treatment of wet or low-pressure gases, a large number of absorption plants have recently been erected for treating small volumes of casing-head gas. Several of these latter plants have been included in this investigation, not because the gas is being utilized for domestic or industrial consumption, but in order to show the relative loss in heating value of gases containing different proportions of gasoline.

[a] Dykema, W. P., and Neal, R. O., Absorption as applied to recovery of gasoline left in residual gas from compression plants: Tech. Paper 232, Bureau of Mines, 1919, pp. 8–11.

[b] Dykema, W. P., Recent developments in the absorption process for recovering gasoline from natural gas: Bull. 176, Bureau of Mines, 1919, p. 11.

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ADVANTAGES OF GASOLINE PLANTS.

As pointed out by other writers,[a] there are advantages of utmost importance to gas producers in having gasoline plants located on their high-pressure lines, aside from the value of the gasoline recovered. Without gasoline plants, difficulty is experienced from condensation of gasoline and water in the lines; the gasoline condensate and vapor disintegrates the rubber gaskets in couplings with resultant large leakage of gas and lowering of pressure; the water frequently collects in low parts of the line and in cold weather freezes, forming constrictions that reduce the line capacity. These difficulties are met by the installation of traps, where gasoline and water are blown out after collecting. Blowing out, of course, represents waste of both gasoline and gas.

These disadvantages react not only against the producer but the consumer as well, because the best service is not assured when large leaks are continually cutting down the pressure and volume of gas. In conjunction with these disadvantages, the gasoline that has condensed in the line is a total loss both to consumer and producer, and represents a large part of the loss in heat units that a gasoline plant would remove from the gas.

Installing gasoline plants on gas lines removes not only the gasoline but also removes water which is present as such and is carried in the lines mechanically. Besides, some water vapor is probably removed from the gas. The proportion of water vapor so condensed would not be sufficient to affect materially the heating value of the gas although it would have that tendency, because the water vapor would absorb some of the heat of combustion. Hence, the installation of gasoline plants obviously eliminates most of the line troubles, gives better service, and yields in the United States probably 100,000,000 gallons yearly of gasoline that would otherwise be lost, and results in a much higher efficiency in the industry.

THEORETICAL CONSIDERATION OF HEATING VALUE.

HEAT UNITS DEFINED.

In the discussion of heating value of natural gas the British thermal unit is used. The British thermal unit, designated briefly as B. t. u., is the amount of heat required to raise the temperature of 1 pound of water through 1° F. at 59° F. and is equivalent to 252 calories.

[a] Wyer, S. S., Natural gas, its production, service and conservation; Bull. 102, pt. 7, Smithsonian Inst., 1918, pp. 25–26; Dykema, W. P., Recent developments in the absorption process for recovering gasoline from natural gas: Bull. 176, Bureau of Mines, 1919, 90 pp.

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The heat of combustion of natural gas is defined by Waidner and Mueller,[a] as follows: "The heat of combustion at constant pressure, of a gas containing only the elements, or compounds of the elements, carbon, hydrogen, oxygen, and nitrogen, is the number of heat units produced by the combustion of unit quantity of the gas initially at a specified temperature and at standard atmospheric pressure, with oxygen at the same temperature and pressure, with formation of gaseous carbon dioxide and nitrogen and liquid water, all cooled to the initial temperature and at standard atmospheric pressure; unit quantity of the gas being the quantity that would occupy unit volume at the standard temperature and standard pressure chosen for gas measurement."

In the same publication the difference between gross heating value, observed heating value, and net heating value are pointed out. In this paper the net heating value is the one used, because in the burning of natural gas the products formed by the combustion are cooled to the initial temperature of gas and air and the water formed remains as a vapor and does not give up its latent heat of vaporization.

The heat of combustion of methane is taken as 970 B. t. u., of ethane, 1719 B. t. u., and of propane, 2464 B. t. u. per cubic foot under standard conditions of pressure and temperature. These figures are given by Richards[b]; they represent, respectively, the net heating value of one cubic foot of each of these gases, with the water formed in combustion remaining uncondensed. Various authorities give different figures than those used. The differences are of no great importance, as regards this paper, because the differential heating values would be little affected by using other factors—that is, the loss in B. t. u. would be practically the same, as the authorities differ by only a few B. t. u.

COMPOSITION OF NATURAL GAS.

Natural gas is composed largely of methane and ethane, with a small percentage of carbon dioxide and nitrogen, the proportion of these constituents differing greatly in gases from different fields, and in gases from different strata. Nearly all natural gas contains also a varying percentage of gasoline vapor. The gasoline vapors are not true gases and can be liquified by pressure at atmospheric temperature, thus differing from methane, which can not be liquified without lowering the temperature below atmospheric. Ethane,

[a] Waidner, C. W., and Mueller, E. F., Industrial gas calorimetry: Technologic Paper 36, Bureau of Standards, 1914, pp. 12–13.

[b] Richards, J. W., Metallurgical calculations, 1918, p. 25.

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when pure, can be liquified at atmospheric temperature by using very high pressure. However, as pure ethane is never found in natural gas, ethane can be classed with methane as a permanent gas. The presence of gasoline vapor in dry gas is probably due to the gas having been in contact at some former period with oil, from which it has taken up some of the lighter fractions. Wet gas or casing-head gas is found in intimate contact with, or dissolved in oil in the "sands" from which the oil is being produced. As the pressure and volumes of gas occurring with oil are usually low, it is possible for the gas to take up larger quantities of the light fractions of the oil than dry gas could that is usually held under high pressure. Hence casing-head gas invariably becomes richer as the pressure decreases or when the well is vacuum pumped. In most instances this same fact applies also to dry gas wells; as the volume and pressure decrease, the gasoline content increases.

DIFFERENCES BETWEEN WET GAS AND DRY GAS.

Dry gas is generally considered to contain less than 1 gallon of gasoline per 1,000 cubic feet, whereas the wet gas contains more. Wells producing large volumes of gas under high pressure always yield "dry gas," largely because of the high pressure, as previously pointed out. The gasoline vapors are made up of pentane, hexane, and various other members of the higher hydrocarbons, all of which have greater heating values per cubic foot of gas than methane or ethane. It is obvious that a gas containing these vapors will have a higher heating value than one without them, consequently when the gasoline is removed, the heating value of the discharge gas will fall. However, as the gasoline in the gas exists as a vapor, and has a definite volume, its removal reduces the volume of the gas to that extent. For example, if a tenth of a gallon of gasoline is removed from 1,000 cubic feet of gas, the total volume of gas will be reduced in heating value equal to the heating value of the gasoline removed, but the volume of discharge gas is only equal to 1,000 cubic feet minus the volume occupied by one-tenth of a gallon of gasoline in the vapor state, or several cubic feet. This reduction of volume compensates in part for the loss in heat units. Besides, as will be shown later (as calculated and as determined by analysis), in dry gas this percentage of loss is very small.

THEORETICAL CALCULATIONS.

The percentage loss can be calculated in a more or less arbitrary manner on the basis of a gallon of gasoline being equal to 30 cubic feet of vapor, and the calorific value of the gasoline recovered being

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119,400 B. t. u. per gallon. This figure is based on the average absorption gasoline which has a gravity of about 80° B. and a heating value of 21,500 B. t. u. per pound. The heating value of gasoline is rarely determined, as this property is not considered important in judging the quality of gasoline, consequently few figures on B. t. u. can be found. Those at hand show values ranging from 20,097 B. t. u. per pound in gasoline having a gravity of 58° B. to 21,269 B. t. u. per pound in gasoline having a gravity of 64° B. These figures differ with different methods of production and as regards refined gasoline differ with the crudes used. However, in general, as the gravity of the gasoline rises the heating value also rises. This is due to the fact that it will take a larger volume of very light gasoline to weigh a pound than a heavier or lower gravity product. Hence it will be seen that the figure 21,500 B. t. u. per pound is logical for gasoline of the gravity obtained in the absorption process, and no appreciable difference in percentage loss would occur should this figure vary slightly.

These factors are practically correct when applied to the average commercial gas. The percentage loss in heating value is then equal to $B-\left\{\frac{B-(A\times 119{,}400)}{1-(A\times 30)}\right\}$, where

$\frac{}{B}$

A=Gasoline extracted per cubic foot of gas.

B=B. t. u. value of gas before treatment in gasoline plant.

119,400=B. t. u. per gallon of gasoline.

This formula is developed as follows: A times 30 represents the quantity of gas equivalent to that of the gasoline removed; subtracting this quantity from 1 gives the quantity of gas left after the gasoline has been removed from 1 cubic foot. A times 119,400 represents the heating value of this quantity of gasoline, and the difference between this product and B represents the heating value of the residual gas; hence this latter figure divided by the actual quantity of gas present gives the heating value of a cubic foot of the gas. Then by subtracting this figure from B, the original heating value of the gas, the loss is obtained, and this in turn divided by B gives the percentage loss.

This formula is accurate in so far as it accounts for heat lost in the gasoline recovered, but it does not include the loss of heating value represented by losses from weathering tank, flow tank, and in uncondensed still vapors. These vapors are largely permanent gases and are removed from the gas by being dissolved in the absorbing oil, but, after this oil is treated in the still, they remain as gases and are uncondensed. A small percentage of this gas which does not condense in the cooling coils is dissolved in the gasoline

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that is produced there, but subsequently is lost again in so-called weathering losses. This gas which is unobtainable as gasoline but, nevertheless, is removed from the natural gas with the gasoline vapors, is of a higher heating value than the original gas, because in the series of hydrocarbons which make up natural gas and gasoline the higher members are more soluble in an absorption oil than the lower members; hence, if a given quantity of "mineral seal oil," in which methane, ethane, propane, butane, pentane, etc., are dissolved, is heated, the first gas to be driven off will be methane, which will be followed by ethane and so on in the order named. In the original absorption this will follow a like course, a larger percentage of the higher members being dissolved than of the lower ones, the whole action depending upon the partial vapor pressures of the different gases.[a]

Consequently these permanent gases in the uncondensed still vapors and weathering tank losses will represent those hydrocarbons removed from the gas that are not liquids at ordinary temperatures and yet are of much higher heating value than the gases that make up the bulk of the original gas. Two examples are submitted herewith, the analysis of the original intake gas and the analysis of the flow-tank gas from the same plant.

Results of analysis of intake gas and flow-tank gas from two plants.

Constituent.	Plant 1.		Plant 2.	
	Intake gas.	Flow-tank gas.	Intake gas.	Flow-tank gas.
CH_4.....per cent..	77.67	51.03	67.48	20.29
C_2H_6.....do....	10.46	32.81	21.31	75.26
CO_2.....do....	1.27	1.14	.41	.57
O_2.....do....	.42	0.00	.95	.68
Residue.....do....	10.18	15.02	9.84	3.19
Total.....do....	100.00	100.00	99.99	99.99
B. t. u. value.....	933	1,059	1,072	1,535

These samples were taken from two plants, the first of which produces 0.17 gallon of gasoline per 1,000 cubic feet of gas treated, and the second, 0.25 gallon per 1,000 cubic feet. In plants which obtain higher yields the difference would be greater, as the propane and butane content is increased with richness of the gas. Naturally, when these richer gases are considered, the results obtained with the above formula will be lower than those obtained in the laboratory.

[a] Dykema, W. P., and Neal, R. O., Absorption as applied to recovery of gasoline left in residual gas from compression plants: Tech. Paper 232, Bureau of Mines, 1919, p. 10.

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A curve (No. 1, in figure 1) was drawn showing the B. t. u. value of intake gases from all the plants considered in this paper. The gasoline content ranges from 0.11 gallon to 4 gallons per 1,000 cubic

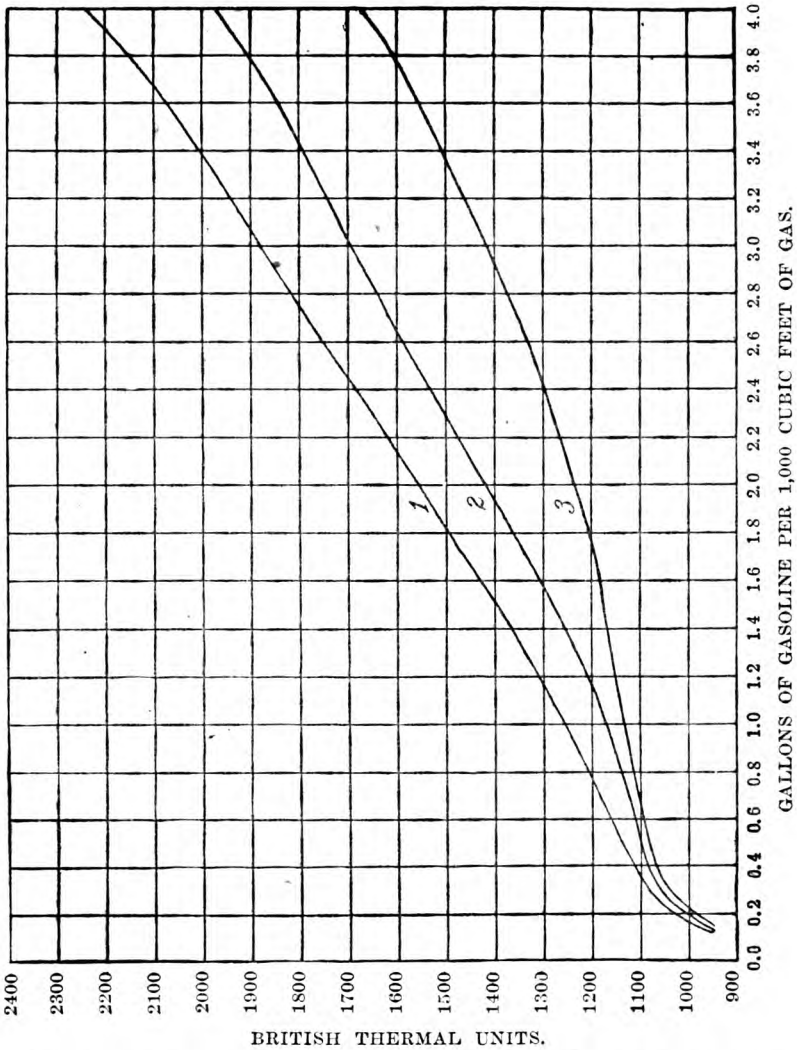

FIGURE 1.—Curves showing heating value of natural gas before and after passing through gasoline plant, for varying gasoline content. *1*, Heat value of intake gas; *2*, Calculated heating value of discharge gas; *3*, heating value of discharge gas as determined in laboratory.

feet. From this curve and from the formula given, Table 1 was calculated, showing the percentage loss in heating value of gases of different gasoline content. This is shown with reference to commercial gases in curve 1 of figure 2.

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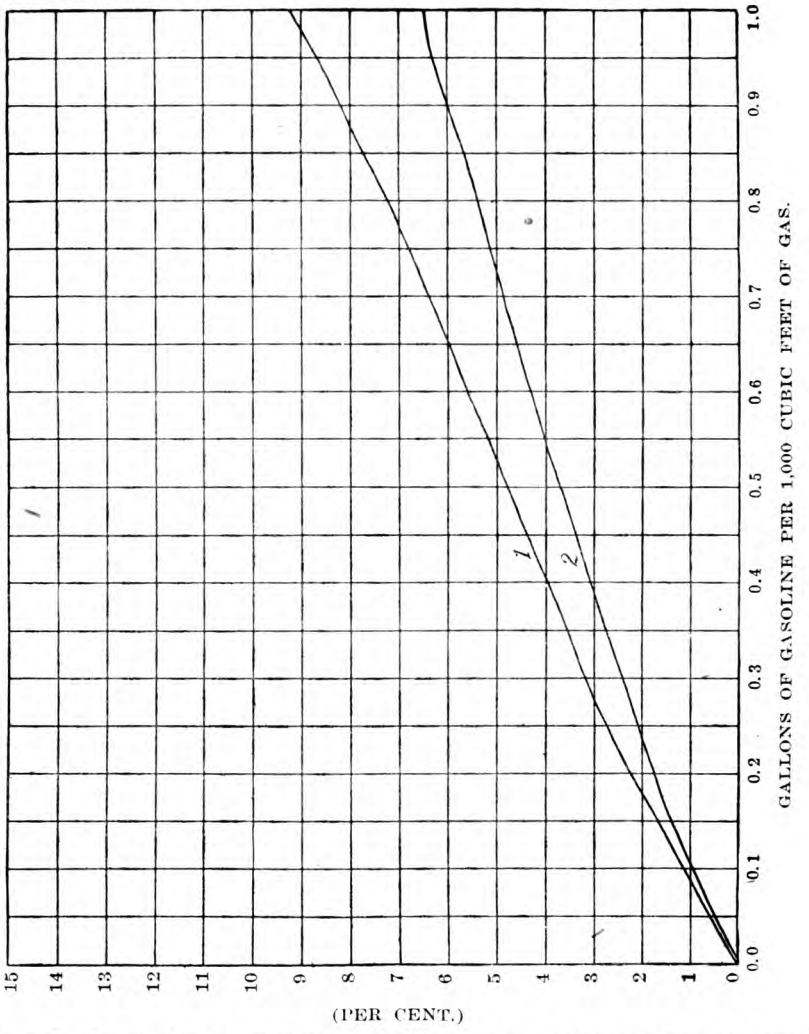

FIGURE 2.—Curves showing percentage loss in heating value of "dry" gases by removal of gasoline. *1*, Percentage loss as determined in the laboratory; *2*, percentage loss as calculated.

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TABLE 1.—*Theoretical loss in heating value of natural gas from removal of gasoline content.*

Calculation based on formula: Percentage loss $= B - \left\{ \frac{B - (A \times 119{,}400)}{1 - (A \times 30)} \right\} \frac{}{B}$

B. t. u. value of intake gas.[a]	B. t. u. value of discharge gas.[b]	Loss in B. t. u. value.	Gasoline recovered, gallons per 1,000 cubic feet.	Percentage loss in heating value, calculated to decrease in volume.
950	941	9	0.1	0.947
1,040	1,032	18	.2	1.731
1,085	1,059	26	.3	2.396
1,137	1,094	43	.5	3.782
1,172	1,115	51	.7	4.863
1,245	1,165	80	1.0	6.426
1,400	1,279	121	1.5	8.643
1,560	1,416	144	2.0	9.231
1,730	1,547	183	2.5	10.578
1,890	1,695	207	3.0	10.950
2,050	1,823	227	3.5	11.072
2,250	1,994	256	4.0	11.790

[a] Obtained from curve 1, figure 1, based on chemical analysis.
[b] Calculated by above formula.

The reader will note that the percentage loss in the heating value of the gases examined increases from 0.947 per cent in gas containing 0.1 gallon of gasoline per 1,000 cubic feet to 11.79 per cent in gas having a content of 4 gallons per 1,000 feet. As commercial natural gas has only a small gasoline content, usually less than 1 gallon per 1,000 cubic feet, it will in general have lost 0.9 to 5 per cent of its heating value, as estimated in this table. Removal from the gas of this amount of gasoline, which as stated before would probably be, in part at least, condensed in the pipe line, reduces the heating value so little that to distinguish the difference in ordinary use would be impossible.

COMPARISON OF HEATING VALUE IN RESIDUE GASES.

Attention is called to the fact that as the percentage decrease in the heating value of the intake gas rises, the discharge gas also increases in heat units. In the last line of the table where 4 gallons of gasoline is obtained per 1,000 cubic feet of gas the discharge gas has a heating value of nearly twice that of the dry gas before being treated. Thus it will be seen that the higher the yield obtained by a gasoline plant the higher heating value the residual gas will have; that is, in a gas of very high gasoline content the residual gas will have a much larger percentage of propane and butane than the discharge of a dry gas, which consists almost entirely of methane and ethane.

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In conjunction with the curve showing the heating value of different gases before treatment in gasoline plants, two other curves are drawn showing the heat value of the gases after treatment. The one (curve 3 in fig. 1) shows the heat value of the residual gas as determined by analysis, and the other (curve 2 in fig. 1) the heat value of the residual gas as calculated by use of the formula.

LIMITATIONS OF CURVES.

It must be understood that this set of curves is no way offered as a method of determining the gasoline content of a gas in preference to standard methods of testing, as each curve represents an average, and individual gases might vary greatly from the curve, such variation being wholly dependent upon the composition. For example, any residual gas from a casing-head plant will have a high B. t. u. value but a low gasoline content. The curves would probably be as valuable an index on the gas as the specific-gravity test, but would be of no further worth, in determining the richness of gas, than to serve as an indication in preliminary work.

EXPERIMENTAL RESULTS IN THE LABORATORY.

Samples of intake and discharge gas were taken from 34 plants; these samples being representative of all the fields, and all degrees of richness of gasoline vapor in natural gas. The heating value of each sample was determined by calculation from the analysis. The tabulated analytical and plant data, arranged as to gasoline content, are presented in Table 2.

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TABLE 2.—*Analysis and plant data.*

Plant index No.	State.	Analysis of intake gas.							Analysis of discharge gas.							Production, gallons per 1,000 cubic feet.	Loss of B. t. u.
		CH_4.	C_2H_6.	C_3H_8.	CO_2.	O_2.	Residue.[a]	B. t. u. (net air-free).	B. t. u. (net air-free).	CH_4.	C_2H_6.	C_3H_8.	CO_2	O_2.	Residue.[a]		
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*			*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		
31	Ohio	72.30	11.92	0.00	0.43	0.00	15.34	905	887	69.58	12.31	0.00	0.24	0.00	17.90	0.0863	18
1	Kansas	77.67	10.46	.00	1.27	.42	10.18	933	923	71.76	13.27	.00	.87	.78	13.32	.17	10
2	Oklahoma	77.42	11.60	.00	.35	.14	10.50	949	936	78.10	10.42	.00	.24	.24	11.00	.18	13
3	Pennsylvania	75.79	11.33	.00	.00	.00	12.00	929	915	73.14	12.00	.00	.36	.24	14.07	.10	14
4	Oklahoma	63.66	21.34	.00	.25	.25	14.48	994	982	66.28	19.74	.00	.51	.25	12.90	.178	12
5	West Virginia	75.30	15.98	.00	.24	.36	7.95	1,004	994	76.25	14.80	.00	.26	.48	8.19	.14	10
6	Oklahoma	63.53	21.67	.00	.23	.59	13.97	1,010	991	66.45	18.97	.00	.39	.26	13.95	.10	19
7	do	71.00	18.54	.00	.16	.61	9.82	1,007	976	66.54	18.24	.00	.49	.36	14.35	.11	31
8	do	64.60	25.09	.00	.69	.41	9.20	1,080	1,053	57.74	20.12	.00	.54	2.73	18.99	.13	27
9	do	76.86	22.13	.00	.32	.00	.64	1,124	1,073	76.14	19.35	.00	.64	.00	3.88	.209	51
10	West Virginia	65.08	22.00	.00	.24	.12	12.57	1,010	992	66.00	20.50	.00	.24	.24	13.02	.220	18
32	Wyoming	66.28	32.93	.00	.79	.00	.00	1,208	1,190	46.42	43.07	.00	.96	.00	9.56	.220	19
11	Oklahoma	67.48	21.31	.00	.41	.95	9.48	1,072	1,027	71.62	18.58	.00	.53	.26	8.98	.250	45
12	do	75.56	23.00	.00	.12	.00	3.32	1,128	1,108	69.35	25.28	.00	.60	.00	4.20	.236	20
13	West Virginia	70.84	24.07	.00	.27	.00	4.81	1,100	1,076	72.61	22.30	.00	.27	.00	4.82	.240	24
14	Oklahoma	51.60	37.20	.00	.25	.40	10.39	1,116	1,086	26.70	10.19	.00	.25	12.01	50.82	.240	30
15	do	64.07	22.36	.00	.00	.00	13.57	1,006	969	63.54	20.54	.00	.00	.62	15.09	.266	27
16	Ohio	70.97	23.23	.00	.16	.00	5.65	1,087	1,041	78.00	16.48	.00	.11	.00	5.38	.399	46
17	Kansas	68.74	20.44	.00	.16	.30	10.30	1,018	976	73.58	15.27	.00	.00	.17	10.90	.343	42
18	Oklahoma	71.20	25.02	.00	.25	.25	3.28	1,120	1,060	74.35	19.75	.00	.36	.00	5.60	.410	60
19	do	65.12	29.42	.00	.12	.24	5.10	1,139	1,082	70.42	23.29	.00	.24	.00	6.05	.383	57
20	Texas	72.60	25.10	.00	.12	.00	2.18	1,136	1,072	76.15	19.31	.00	.24	.12	4.18	.400	64
23	California	54.30	37.65	.00	7.20	.12	2.80	1,174	1,109	56.00	32.90	.00	7.40	.55	3.45	.500	65
24	Oklahoma	51.73	37.16	.00	1.62	.40	9.64	1,145	1,112	56.49	32.88	.00	2.02	.81	7.80	.710	33
21	California	52.10	36.90	.00	8.30	.12	2.49	1,141	1,080	55.61	31.40	.00	8.50	.00	4.49	.690	61
22	Oklahoma	50.40	44.27	.00	.25	.25	4.83	1,250	1,160	54.50	36.72	.00	.25	.12	8.41	.900	90
25	do	43.59	49.78	.00	6.63	.00	.00	1,278	1,179	43.50	44.00	.00	7.10	.45	4.95	.900	99
26	do	.00	17.53	82.63	.95	.00	.00	2,342	1,386	36.91	59.90	.00	.59	.00	2.59	3.000	66
27	do	42.84	52.98	.00	.32	.00	3.86	1,332	1,216	55.76	39.28	.00	.68	.00	4.28	1.000	116
33	do	31.93	54.48	.00	.31	1.62	11.68	1,273	1,133	37.60	44.70	.00	.25	.25	17.20	1.130	140
28	Kansas	.00	56.73	25.43	1.47	.00	16.38	1,602	1,295	14.12	67.38	.00	.00	.00	18.50	1.500	407
29	Oklahoma	.00	86.64	7.98	1.00	.00	4.35	1,686	1,192	57.06	37.27	.00	.99	.00	4.75	2.000	494
30	California	36.22	49.70	.00	9.35	.26	4.40	1,210	1,017	47.45	32.50	.00	12.20	.00	7.85	2.250	193
34	Oklahoma	.00	42.99	43.43	.44	3.43	9.73	2,172	1,995	.00	62.09	10.17	.50	6.71	20.41	5.300	177

[a] Residue contains inert gases, largely nitrogen.

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METHOD OF OBTAINING HEAT VALUE OF GAS.

The analyses in the table show all hydrocarbons calculated to either methane and ethane or ethane and propane. This calculation is slightly misleading as all of these gases contain higher members of the hydrocarbons in varying proportions. However, methane and ethane represent the larger part of the hydrocarbons present, and it is impossible to determine more than two members of the series in a combustion analysis.

As all hydrocarbons present are accounted for as methane and ethane, the figure for methane is lower and that for ethane is higher than the true value. With the richer gases, the percentage of methane diminishes and the ethane content increases, until the gas will not calculate to methane and ethane, then it is calculated to ethane and propane.

This method of determining the heating value of natural gas probably gives more accurate results than those obtained from the use of a flow calorimeter. In the latter method there are many factors that may cause error, and it is generally conceded impossible to get analyses that will check within 1 per cent, which amounts to 10 B. t. u. with an ordinary dry gas. As there is only about 10 B. t. u. difference in intake and discharge gas of this character, it is possible to obtain results showing the discharge gas to have the same heating value as the intake or even greater, should experimental error lie in that direction. Computations from analysis, however, can be checked within one-half of 1 per cent, which makes more accurate determinations possible.

In determining a very rich gas with the calorimeter, difficulty is often experienced in getting complete combustion, and frequently determinations are made when the flame is quite luminous from incomplete combustion. An example of this was cited recently where a gas technologist found a calorimeter being operated with a luminous flame; by adjusting the burner for the operator an increase in the heating value of the gas of about 150 B. t. u. per cubic foot was recorded.

In a series of 54 determinations by both calorimeter and analysis, the writer found that the calorimeter values ran from 1.1 per cent lower to 2.2 per cent higher than the calculated B. t. u. values from chemical analysis, and in the average of these 54 determinations the B. t. u. value as found with the calorimeter was 0.3 per cent higher than that determined by the analysis.

COLLECTION OF SAMPLES.

Because of these facts the collection of samples from gasoline plants was greatly simplified; a 12-ounce bottle sufficed for the sam-

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ple of gas for analysis whereas a steel cylinder of gas would be required for the calorimeter determination.

DISCUSSION OF ANALYTICAL RESULTS.

In the results tabulated in Table 2 there are several seeming contradictions; a gas of high heating value yielding less gasoline than one of lower heating value, and the loss in heating value of the former being very high compared with the amount of gasoline produced. However, these variations are probably due to different percentages of propane and butane, which, although they increase the heating value, are never obtained in large proportions as gasoline. Variations are greater and more noticeable in several of the very rich gases. The analytical error is probably greater in these gases, as nearly all of them are drawn from wells under high vacuum, and many of them are contaminated with air from leaks in the line, in fact, it is not unusual for gas which is pumped under a vacuum to contain 40 per cent air or even more. Small proportions of air will not affect the analysis appreciably, but when the air content becomes higher than 2 or 3 per cent the experimental error becomes large, as the air content is determined by the oxygen content multiplied by five, and the error is proportionately increased. It will also be noticed in comparing the analyses of the intake and discharge gas, that in most gases the methane content increases while the ethane value falls; in some of the very dry gases this is not the case, but in general it holds true.

AIR CONTENT OF NATURAL GAS.

Frequently plants are handling gas having a much higher air content than is realized and the data given on production and gas volumes treated must be corrected. Also in many plants the permanent gases that are dissolved and later escape in weathering are not considered with regard to production, yet they are effectual in decreasing the calorific value of the gas. This point is probably the largest factor in causing the variance of results shown in Tables 1 and 3, because the figures in Table 1 do not consider this loss. This difference is shown in the curves of figure 2 (p. 14).

GENERALIZATION.

In generalizing the results from the table of analysis and plant data, averages were taken as indicated in Table 3, and a curve (No. 2, fig. 2) was developed from the averages showing the percentage loss in heating value. By so doing individual differences are minimized and analytical errors are compensated.

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TABLE 3.—*Generalization of Table 2.*

Number of plants, and average production of gasoline in gallons per thousand cubic feet	B. t. u. value of intake gas.	B. t. u. value of discharge gas.	Loss in B. t. u.	Gasoline recovered, gallons per 1,000 cubic feet.	Percentage of loss in heating value, calculated to decrease in volume.
Nine plants producing between 0.086 and 0.18 gallon	952.0	939.0	13.0	0.115	1.76
Eight plants producing between 0.209 and 0.266 gallon	1,078.2	1,048.2	28.2	.234	2.61
Ten plants producing between 0.343 and 0.9 gallon	1,148.8	1,087.0	61.8	.573	5.38
Five plants producing between 1.0 and 2.25 gallons	1,420.6	1,170.6	250.0	1.580	17.60
Two plants producing between 3 and 5.3 gallons	2,257.0	1,690.0	567.0	4.100	25.10

Curve 1 in figure 2, showing the percentage loss in heating value of dry gases after treatment in gasoline plants, as determined by analysis, is offered for comparison with curve 2, figure 2, which represents the same loss as determined by calculation.

The reader will note that these two curves differ only slightly. As the curves cover practically all commercial gas it can readily be seen that the loss in B. t. u. value through the extraction of gasoline is so small as to require refined laboratory apparatus for its determination.

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